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LOW ENERGY X-RAY MASS ATTENUATION COEFFICIENTS FOR RADIATION 850 TO 3000 eV IN SELECTED ELEMENTS WITH Z=6 TO Z=18

By

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An essay submitted to the Faculty of Philosophy of
The Johns Hopkins University
in conformity with the requirements for the degree of
Master of Arts

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ABSTRACT

The attenuation of X-rays with energies from 853 to 2991 ev by an Aluminum film, and C_2H_4, N_2, O_2, Ne, and A gases has been measured using a beryl crystal monochromator. Experiment has led to the determination of mass attenuation coefficients with less than two percent probable error obtained by low kilovoltage operation of the X-ray tube and by flow proportional counter detection with pulse height discrimination. Some features of flow proportional counting using He-A-CH_4 gas are discussed. Also a comparison of this work with previous determinations of a few experimental values in this X-ray region are included.

TABLE OF CONTENTS

A. Interaction of Soft X-rays with Matter Page 4

B. Experimental Methods Page 8

  1. X-ray Source Page 9

  2. Single Crystal Monochromator Page 11

  3. Attenuators Page 14

  4. X-ray Detector System Page 17

C. Experimental Results Page 19

  1. Observations and Computations Page 19

  2. Measurements Page 23

D. Previous Measurements and Conclusions Page 25

Acknowledgements Page 27

Vita Page 28

References Page 29

A. Interactions of Soft X-rays with Matter

The three interactions which are in general responsible for the attenuation of X-rays by matter are:

1. Photoelectric absorption
2. Thomson Scattering
3. Compton Effect

The above processes have different Z and $h\nu$ dependence, and in the present area of interest, attenuation is due almost exclusively to true or photoelectric absorption with only minor corrections due to Thomson scattering. There is no measurable effect due to Compton scattering. Hence a determination of the mass attenuation coefficient leads directly to the photoelectric cross section, which can be compared with theoretical calculations. Absorbing elements of low atomic number are of particular interest in this respect due to the relative simplicity of their wave functions when compared with heavier elements.

A well collimated beam of monochromatic X-radiation exhibits exponential absorption. Two phenomena account for this: one, photons are absorbed or scattered in a single event; two, the number of photons which undergo either of these interactions in traversing a differential thickness of matter is proportional to the number of incident photons.

In the X-ray energy region of the present work the photoelectric absorption is responsible for roughly 99% of all interactions. Scattering becomes negligible for wavelengths in excess of 1.5A when the absorbers have Z in excess of 13; as is the case for wavelengths greater than 2.5A when Z is larger than 6.[1] As has already been mentioned Thomson scattering provides the only measureable correction in the energy region of interest. Thomson treated the scattering of low $h\nu$ photons by free electrons using non-relativistic theory to arrive at a value for the total scattering cross section of incident radiation which is independent of wavelength.

$$\phi = \frac{8\pi e^4}{3m^2c^4}$$

The value for the above is 6.65×10^{-25} cm^2/atom where e is the charge on an electron in electrostatic units, m is its mass in grams, and c is the velocity of light in cm/sec. This can be expressed in more convenient units as .665 barns/atom where the barn is 10^{-24} cm^2. That this value is indeed small is seen from a comparison of it with the measured mass absorption coefficients for Ethylene gas which range from 3670 to 139,000 barns per atom in the area of study. These figures point out the validity of a direct conversion from mass attenuation coefficients to the photoelectric cross section.

Photons can not be totally absorbed by a free electron. Such absorption can only occur when the target electron is initially bound in an atom. In this case momentum is conserved with the recoil of the nucleus. Furthermore, it is the more tightly bound electrons that have the greater probability for absorbing an X-ray, and in those cases where $h\nu$ exceeds E_k, the K shell electrons account for about 80% of the total absorption. The absolute probability of photoelectric interaction is described in terms of the atomic cross section and is expressed in cm^2/atom. Most theories to date deal only with K absorption, the partial effect due solely to the interaction with electrons in the innermost shell, and are generally corrected to give the total cross section of the atom through multiplication by 5/4ths. This factor compensates for the 80% K shell absorption. In addition to the fact that cross sections vary with $h\nu$ and Z, further complications occur in the region of the so called absorption edges. These edges result from the fact that photons are no longer able to eject electrons belonging to a specific subshell. The first such edge reached with decreasing incident photon energies is that for the K shell. Below this energy quantative theoretical data has been difficult to obtain.

In the case of light elements where the dimensions of the electron distribution is roughly equal to or greater than the X-ray wavelength, the intensity of the scattered X-rays is proportional to the atomic number Z. In this case each electron scatters separately and not in phase. When measuring the total scattered intensity the individual intensities due to each electron are added together. For longer wavelengths all of the atomic electrons tend to scatter in phase. The resultant field vector of the scattered radiation for all of the electrons is then squared to yield the intensity of the scattered radiation which is roughly $Z^2\phi$.

B. EXPERIMENTAL METHODS

Precise determination of the mass attenuation coefficients requires the use of a collimated, monochromatic beam of radiation. When more than one wavelength is present the fraction of energy removed per unit thickness decreases with increasing path length, and μ is found to depend upon the absorber thickness. A narrow, collimated beam is necessary to prevent once scattered radiation from remaining in the beam and thereby being detected.

When a monochromatic beam of intensity, I, traverses a differential thickness of material, the emergent beam is decreased by an amount dI. Such a relation can be expressed after a simple integration by the relation $I/I_o = e^{-\mu_m \frac{m}{A}}$ where μ_m is the mass absorption coefficient and $\frac{m}{A}$ is the mass per unit area of absorber in the radiation path. From the fact that the exponent is dimensionless, μ_m is expressed in the units of cm^2/gm. The atomic attenuation coefficient which is $\mu_m \frac{A}{N}$ ($\frac{A}{N}$ is the atomic weight of the absorber divided by Avagadro's Number) has units of cm^2/atom or barns/atom. If compounds are used as absorbers, the molecular absorption coefficient is usually defined, as in the case of Ethylene gas, C_2H_4; $\mu_{mol} = 2(\mu_a)_C + 4(\mu_a)_H$, where μ_a for hydrogen is equivalent to the Thomson cross section.

The apparatus which is to determine most accurately the attenuation coefficients must satisfy the below conditions.[2]

1. Incident photons which interact in any fashion other than small angle scattering must not be allowed to reach the detector.

2. Any X-ray photon removed from the beam must be removed by one and only one interation.

3. The number of interactions, and hence the energy absorbed by the attenuating material, must be small so as not to affect the physical state of the attenuator.

4. All X-rays detected must pass through the same amount of attenuator within a statistical accuracy in excess of the statistics imposed by the counting process.

5. No X-ray photon which has undergone an interaction must be deflected into the counter by the attenuating material or parts of the experimental equipment.

1. Source of X-rays

The attenuator-in attenuator-out method necessary to determine I/I_0 requires a high stability X-ray source. Also the fact that higher order radiation with wavelengths of $\lambda/2$ and $\lambda/3$ can introduce errors makes it necessary to operate the tube at low voltages and therefore high currents in order to obtain the necessary intensity, see Table 1. The X-ray tube employed was the same one used by Alan J. Bearden except that a Varian VAC-ION pump was used to provide dynamic pumping to maintain a vacuum of better than 10^{-6} mm of Hg.[2] The various targets required to provide the desired characteristic radiation were easily interchanged due to the satisfactory

use of Teflon "O" rings to seal the tube. Individual targets were soldered to water-cooled, copper assemblies except in those cases where soldering became excessively difficult. In particular, Mg and Al assemblies similiar to those made of copper were machined from the target metal.

Radiation was taken off at an angle of six degrees from the surface of the target through a three inch long by one quarter inch diameter tube on the end of which was mounted a Mylar window. In addition to providing a degree of collimation, the tube served as a mount for a magnetic electron trap designed to deflect electrons scattered from the target that might otherwise damage the Mylar film separating the highly evacuated X-ray tube from the spectrometer. The addition of such a trap was found to increase the lifetime of the highly transparent Mylar from several hours to a number of months.

For radiation with wavelengths in excess of 5A, the attenuation due to 0.3 mil Mylar film approaches 90%. Where two thicknesses are needed in the radiation path, the intensity without gas absorption is reduced to approximately 1%. In hopes of gaining more intensity, a plan to stretch the Mylar thereby reducing its thickness was carried out with success. A piece of the film was stretched over and glued to the thoroughly cleaned end of a 1.5 inch diameter brass

tube thereby producing a vacuum seal.[3] The other end of the same tube was connected to a fore pump through a valve which permitted slow evacuation of the volume. In the process the Mylar film was stretched from a plane configuration to that of a hemisphere with an associated reduction in thickness by a factor of three. From the fact that any further stretching caused breakage, it is reasoned that 0.1 mils is the minimum thickness which could be made to support a vacuum. Despite the increase of intensity by a factor of nearly eight, it was only necessary to increase the radiation wavelength to approximately 15A to produce new transmission difficulties.

Table 1. The High Voltage and Filament Current requirements for the various characteristic radiations.

Target, Line	$h\nu$	X-Ray Voltage	X-Ray Current
Ag Lα	2991	6.0 kev	5.0 ma
Mo Lα	2298	6.0	5.0
Al Kα	1490	5.0	2.0
Al Kβ	1556	6.0	30.0
Mg Kα	1256	5.0	4.0
Zn Lα	1014	5.0	6.0
Cu Lα	932	3.5	20.0
Ni Lα	853	3.5	17.0

2. The Single Crystal Monochromator

A single crystal vacuum spectrometer was constructed employing various sizes of brass tubing to provide an evacuated path from the X-ray tube to the detector. See Fig. 1.

Basically it was composed of a casing about the crystal holder and two long pieces of tubing used to provide an evacuated or gas filled path for the radiation under study. The length of each of the two tubes which connected the X-ray tube to the crystal casing thence to the proportional counter was chosen to be 50 cm., thus providing a total absorber path length on the order of 110 cm. The choice of this length represents a compromise dependent upon the desire to utilize a single apparatus throughout. In the case of more energetic radiation it was necessary to provide ample attenuation without requiring gas pressures in excess of one atmosphere. On the other hand, for long wavelengths it was necessary to make the path sufficiently short to allow measureable pressures of the attenuating gas while maintaining a reasonable level of transmission. The tube length had to be sufficiently long to give the desired resolution with obtainable slit widths. An early study with this spectrometer employing a 1 mil slit at the entrance to the proportional counter showed that it could resolve the Ag L_{α_2} line of the $L_{\alpha_{1,2}}$ doublet to a degree comparable with the double crystal measurements of Parrat.[4] Later with the weak Al K_β line a five mil slit was substituted to obtain the desired intensity. There was a resultant loss of resolution which made it impossible to obtain absorption

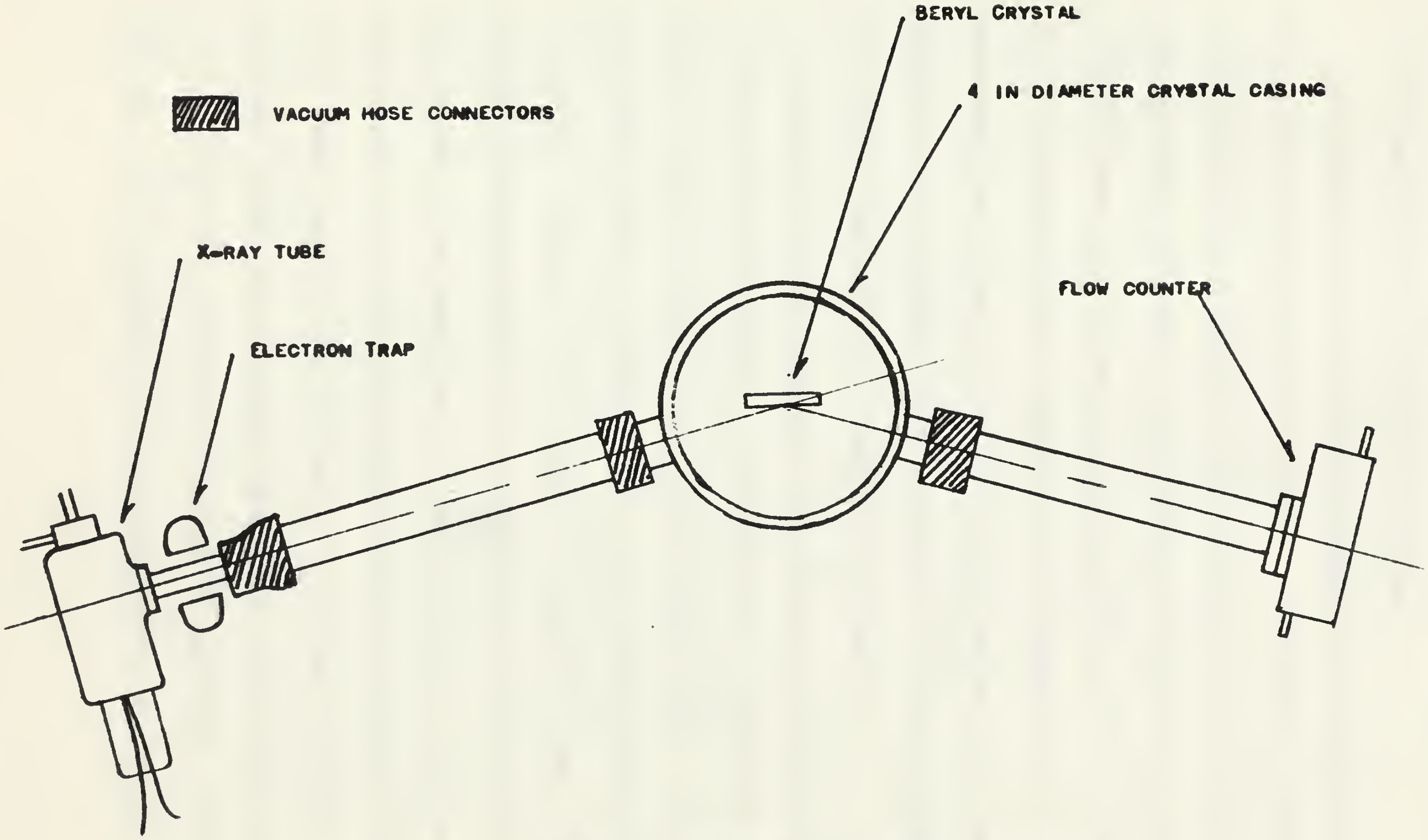


FIGURE 1. SINGLE CRYSTAL VACUUM SPECTROMETER

information for an Aluminum absorber with this radiation. A further opening, in excess of 5 mils, caused no difficulties in the case of Zn, Cu, and Ni radiations.

To insure the use of correct wavelengths, characteristic radiation was employed throughout. The additional intensity of characteristic radiation over continuous (10:1 for Al K_α) speeded data collection. The excessive wavelengths of the radiation used in this study allowed little choice so far as to what crystal would be employed. From Bragg's Law it is necessary that twice the lattice spacing exceed the wavelength of the radiation to be reflected. A Beryl crystal ($d = 7.96A$) was chosen for these measurements.

Several interchangeable vacuum casings to fit around the crystal and its holder were constructed to suit one or more of the characteristic radiations under study. The spectrometer was so arranged as to allow evacuation by a fore pump in series with a liquid nitrogen cold trap capable of reducing the pressure within the spectrometer to the order of a micron. The spectrometer, once evacuated, could be maintained at any desired pressure between atmospheric and the minimum pump inlet pressure. For the more energetic radiation relatively large gas pressures were required and a mercury manometer was used to measure the pressure differences between the attenuator-in and attenuator-out conditions. With

increased wavelengths the gas pressures of the attenuating gases were reduced. Above 5A the pressure differences required to give the desired attenuation fell below 5cm of Hg and an oil manometer had to be introduced to ensure no more than a 1% error in pressure determination. Apiezon "B" oil, with a specific gravity of .863, was used after being completely deaerated. An improvement in sensitivity by a factor of 15 was realized as a result of this change.

3. Attenuators

The absorbers must be sufficiently removed from the entrance to the detector to insure that only the radiation which is either unaffected or at most deflected through small angles can reach the sensitive volume of the counter. To ensure this the solid absorber was located immediately following the crystal in the path of the radiation, some 50 cm from the counter window. For gaseous absorbers which fill the entire path, only the last few centimeters can produce scattering which could possibly be detected. This is of no concern due to the predominance of photoelectric absorption.

The average mass attenuation coefficient, $\langle\mu\rangle$, the absorption cross section, σ, and the statistical mean of the amount of matter traversed, $\langle N\rangle$, are given in the following relation: $\langle\mu\rangle = \sigma\langle N\rangle$.[2] Since the cross section is an exact parameter of an atom, it is important that the error in $\langle N\rangle$

be much smaller than that encountered in making the measurements. Gases present little or no problem in this respect, but it is important that the solid absorbers be of uniform thickness, and without pits or pinholes in the case of thin foils. The mass per unit area is then determined by weighing the foil and dividing by the cross sectional area. The density is assumed to be known from previous determinations.

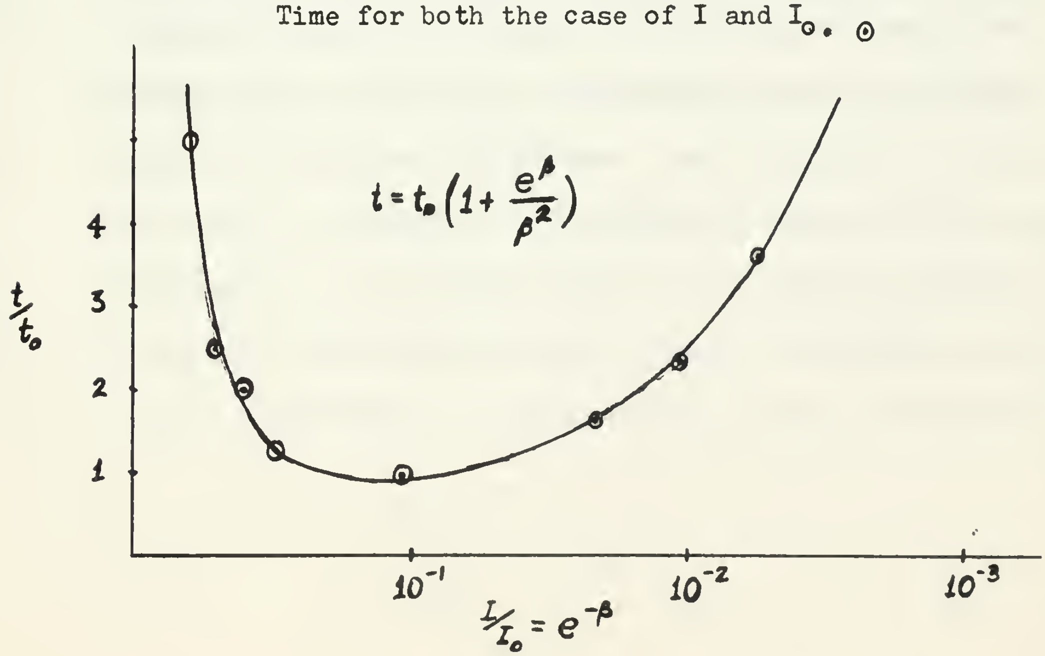
A consideration of importance where low Z absorbers are used, and particularly in the region of soft radiation, is that of the purity of the absorbers. Small quantities of heavy impurities in a light absorber can substantially affect the accuracy of the measurements. For the purity of the absorbers used in this experiment see Table 2.

Table 2. Purity of Absorbers used for Attenuation Measurements

Attenuator	Percent	Percent of Impurities
Ethylene (C_2H_4)	99.5 or better	Unspecified
Nitrogen (N_2)	99.996	Oxygen and Hydrogen
Oxygen (O_2)	99.8	0.1 CO_2 0.01 A, N_2 & H_2
Neon (Ne)	99.96	0.03 He 0.01 N_2 0.0005 H_2 & O_2
Aluminum (Al)	Unknown	Cochran Foil Co.
Argon (A)	99.98	0.02 N_2 0.0005 H_2 & O_2

Having chosen the absorbers it is necessary to decide on the optimum thickness so as to generate the most precise results in a minimum of time. For the problem of photon counting with absorber-in and absorber-out on consecutive runs, Alan J. Bearden has developed a relationship which gives the desired percent transmission for the fastest data accumulation, and the relative lengths of time to be spent collecting the attenuator-in and attenuator-out information.[2] It is found that the optimum value for I/I_o is 0.109 in which case both I and I_o should be measured over equal lengths of time. For other ratios of I to I_o, the relative amounts of time to be spent collecting data can be taken directly from Fig. 2, which is also an outgrowth of Alan J. Bearden's statistical analysis.[2] The same curve should be referred to in making the background count studies.

Figure 2. Optimum Attenuator Thickness and Data Collection Time for both the case of I and I_o.



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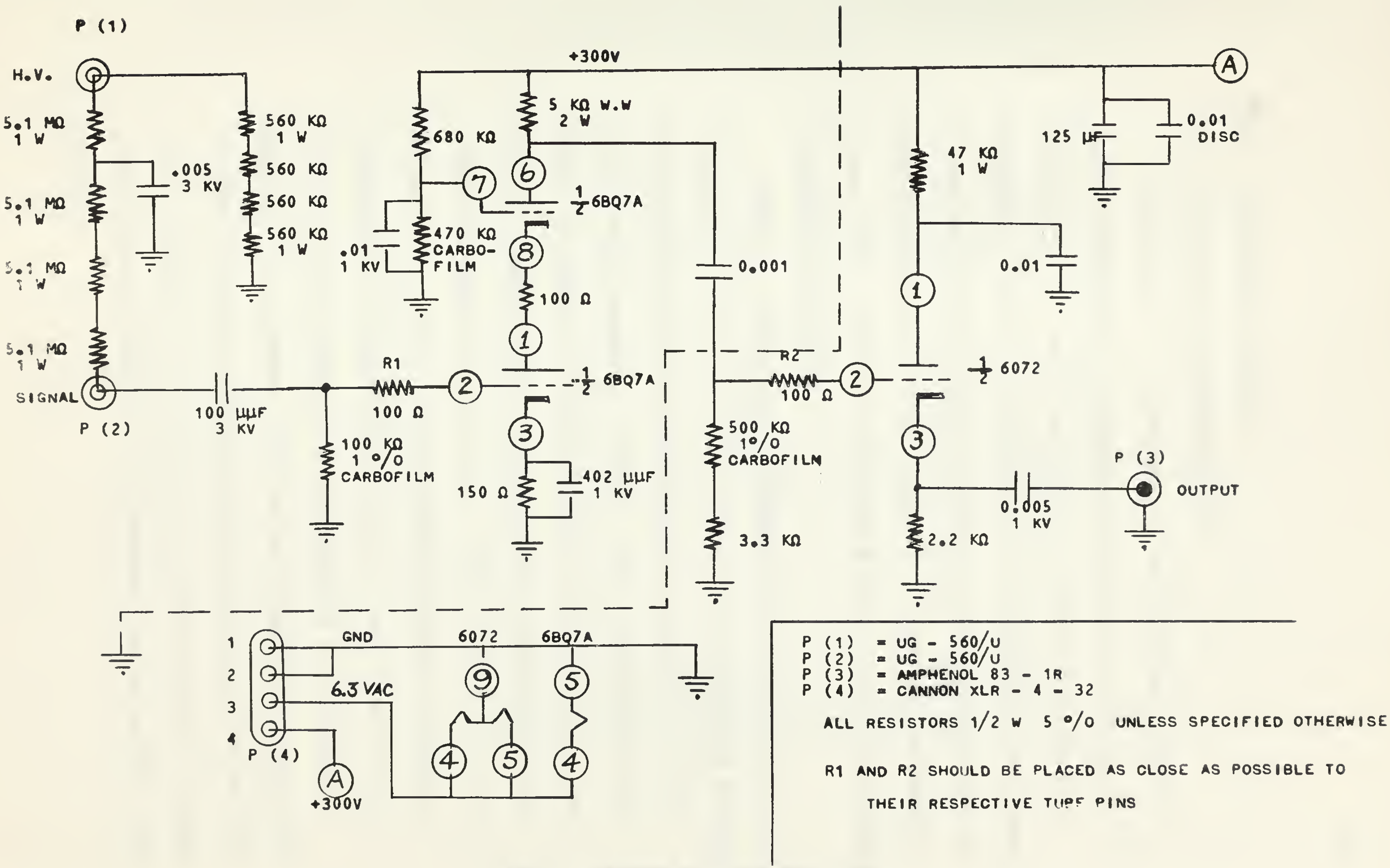
4. X-Ray Detector System

The proportional counter was selected for the soft X-ray detection because it is energy selective, and highly efficient as well as having output pulses considerably above background noise level. For wavelengths above 5 A the efficiency of the Argon-Methane counter is greater than 50% and it increases to approximately 100% for wavelengths in excess of 8A. Above 10A, large portions of the radiation can be absorbed in a dead space at the entrance to the Argon counter where the electric field is greatly reduced. In such regions primary electrons are not rapidly accelerated and recombination can occur resulting in reduced gas multiplication at the wire with poor resolution and a loss of counts. The above effect can be greatly reduced with the introduction of relatively transparent Helium so that the bulk of the absorption occurs in the sensitive volume producing a full sized pulse. A noticeable effect in this direction was observed as a result of discharging a full bottle of Helium gas into a nearly empty bottle of 90% Argon, 10% Methane. Such a mixture is only of use where the wavelength is sufficiently long that the counter efficiency is not greatly reduced. The article by Hendee, Fine, and Brown should serve as a guide in determining the desired percentages in a mixture such as Helium and Argon.[5]

A side window, cylindrical construction counter was built with a piece of stainless steel tubing of 7/8 inch inside diameter and an anode of 0.002 inch platinum wire. The counter needed, in conjunction with it, a high-quality linear amplifier; and the use of a pulse height selector required that the proportional counter voltage be maintained constant. The High Voltage Regulator used in this experiment was capable of stability to one part in 10^5 under normal operating conditions.[6] The output of the proportional counter went to a Cascode linear preamplifier designed with a gain of 50, by Alan J. Bearden to give the desired high signal to noise ratio needed in this experiment. See Fig. 3 for the wiring diagram. Further amplification and pulse height discrimination were provided by a Hamner amplifier and its related single channel pulse height selector.[7] A choice of amplification between 20 and 3200 provided the optimum output voltage to allow proper discrimination. The data collection was done with a 4000 cycle electronic clock and a decade scaler.[8]



P (1) = UG - 560/U
P (2) = UG - 560/U
P (3) = AMPHENOL 83 - 1R
P (4) = CANNON XLR - 4 - 32

ALL RESISTORS 1/2 W 5 °/o UNLESS SPECIFIED OTHERWISE

R1 AND R2 SHOULD BE PLACED AS CLOSE AS POSSIBLE TO THEIR RESPECTIVE TUBE PINS

FIGURE 3. CASCODE PULSE PREAMPLIFIER

C. Experimental Results

1. Observations and Computations

Preliminary to a discussion of calculations, consider a typical analysis of μ_m involving Neon gas as an absorber. The intensity of the radiation should not exceed that which is compatible with the recovery time of the counter. The pressure in the spectrometer should be chosen so as to produce the desired attenuation, and the relative time spent in collecting I_o and I data should be as discussed in the section on optimum attenuator thickness.

Prior to making any measurements the spectrometer should be flushed with the gas to be studied by successively filling and evacuating until all impurities are removed. With the spectrometer evacuated, a total of more than 10,000 counts should be taken for a determination of I_o. This will yield a 1% statistical error. Next fill the spectrometer to the desired pressure and determine I. This data should be collected over a period of time dependent upon the percent of transmission as determined in Fig. 2. Next repeat the I_o count followed by another I determination at a slightly different gas pressure. For the most expeditious collection of data, I should be chosen in the range between 10 and 40% of I_o. Finally, in calculating I/I_o each value of I is compared with the average of the preceding and succeeding values for I_o.

A collection of sample data appears in the two tables below. The radiation is Zn L_α and the absorbing element is Neon.

Table 3. Rough Data Accumulation

t (sec)	press (cm of oil)	counts
10	0	19391
20	8.6	263
10	0	19461
20	9.05	194
10	0	19241
20	7.15	529
10	0	19092
20	7.6	418
10	0	19366
20	6.65	728
10	0	19307
10	5.6	634
10	0	18871
10	5.55	665
10	0	19855
20	4.8	2125
10	0	19541
20	6.0	1093
10	0	20007
20	7.3	456
10	0	20398

Table 4. Data Reduction

I_o	I	I/I_o	$\mu_m \frac{m}{A}$	press cm oil	$\frac{m}{A}$	μ_m	deviation
3885	26.3	.00677	4.995	8.60	6.674	7485	215
3870	19.4	.00501	5.296	9.05	7.024	7540	160
3833	52.9	.01380	4.283	7.15	5.549	7719	19
3846	41.8	.01087	4.522	7.60	5.898	7667	33
3867	72.8	.01883	3.972	6.65	5.161	7696	4
3818	127.0	.03326	3.403	5.60	4.347	7829	129
3873	133.0	.03434	3.371	5.55	4.307	7828	128
3940	213.0	.05406	2.918	4.80	3.725	7834	134
3955	109.0	.02756	3.591	6.00	4.657	7712	12
4041	45.6	.01284	4.355	7.30	5.666	7687	13
					Total	76997	847
					Ave	7700	± 85

The results of this paper are expressed in terms of the average value plus or minus the average deviation. This average deviation is equal to $\sqrt{n-1}\,\sigma$, which turns out to be three probable errors for this study. It is expected that one half of the calculated values will be within one probable error of the average value.

In the calculations, background corrections, where they were significant, have already been subtracted from both I and I_o in Table 4. It was possible to neglect any consideration of background except in the region of least energetic radiation, above 10A, where the counting rate was substantially reduced and where discrimination between the output signal and the background noise became more difficult.

The procedure used to arrive at a value for the mass per unit area of the aluminum absorber involved the following: first the foil which was approximately seven microns thick was placed between two pieces of lucite and turned on a lathe to a diameter of .850 inches. The remaining disc was weighed on a micro-balance to an estimated accuracy of one micro gram. The weighing was performed by Joseph Walter on the micro balance designed by Prof. Corwin of the Chemistry Department of this university. From the results of the weighing, and a calculation of the circular area, the mass per unit area was calculated to be 1.574 milligrams per cm^2.

2. Measurements

Observations made with the previously discussed apparatus led to the values, in Table 5, for mass attenuation coefficients which are not corrected for scattering. In the case of Ethylene gas, the molecular attenuation coefficient is given without regard to the hydrogen present, which has only a minor effect on the attenuation.

Table 5. Mass Attenuation Coefficients in units of cm^2/gm with their average deviations.

Radiation	C_2H_4	N_2	O_2	N	A	A
Ag L_α	78.7±1.5	149±4	220±7	423±10	745±7.	174±6
Mo L_α	158.±9	318±4	419±5	770±5	1600±10.	316±3
Al K_α	619.±5	1150±30	1610±20	2760±30	390±6	1150±20
Al K_β	531.±8	981±16	1380±20	2420±40	( )	1030±20
Mg L_α	1010.±20	1830±10	2520±30	4320±50	632±6.	1770±40
Zn L_α	1880.±20	3430±100	4340±20	7700±90	1150±10	3200±40
Cu L_α	2370.±20	4470±100	5510±50	9790±80	1440±20	4040±40
Ni L_α	2970.±60	5300±80	5580±210	747±23	1830±20	4590±120

The above determined mass attenuation coefficients are considered to be accurate within a two percent probable error. This estimate is based upon a calculation of the average deviation as done in the sample data study. Only one value, that for Oxygen using Ni L_α radiation is believed to be unreliable. Repeated attempts to obtain this value have shown inconsistencies and a general trend toward smaller values than

what might be expected from extrapolation. The reasons for this discrepancy are not understood. No value for the absorption coefficient of Aluminum with Al K_β radiation was determined due to the close proximity of the Al K absorption edge to the weak K_β characteristic line. A reduction in resolution of the spectrometer was necessary in order to pass the desired amount of radiation. As a result, radiation on both sides of the edge was detected giving faulty results.

D. Previous Measurements and Conclusions

Monochromatization, detection, and purity of absorber were the major problems of the early experimenters interested in studying X-ray absorption. The first measurements of interest for the purpose of comparison with the present work were done in 1930 by Woernle.[2] Using a vacuum spectrometer and an ionization chamber for detection he measured the mass absorption coefficients for low Z gases in the range of 2 to 10A. In 1938, C. L. Andrews undertook a study of X-ray absorptions employing radiation between 1.5 and 8.3A in an attempt to check the earlier work of Jonsson and Biermann.[1] In his paper he mentions the superiority of the ion chamber over photo detection as a means of studying relative X-ray intensities. He also points out that studies on either side of the absorption edge of expected heavy impurities will confirm their presence, and in many cases allow a determination of their concentrations. The most recent experimentation in this field has been done in this laboratory by Alan J. Bearden for X-ray wavelengths up to Ag L_α doublet.[2] The present paper is in fact an outgrowth of Dr. Bearden's earlier work, using procedures outlined by him on an apparatus initially installed with his assistance. The measurements with Ag L_α radiation were made so as to overlap and provide a basis for comparison with his work.

Table 6. Earlier Determinations of Mass Attenuations Coefficients of Interest for Comparison[9].

	C	N_2	O_2	Ne	Al	A	
Ag L_α	89.4	149	223	421	774	203	AJB
		144	222	416		174	W
					822		CLA
Mo L_α		312	476	865		360	W
					1630		CLA
Al K_α		1109	1585	2750		1157	W
					459		CLA
Mg K_α		1796	2540	4310		1865	W

AJB: Dissertation, 1958 JHU, Baltimore, Md.
W: Ann D Phy 5, 475 (1930)
CLA: Phys. Rev. 54, 994 (1938)

Noteworthy in the comparison of this study with the earlier works of Andrews and Woernle is the fact that modern detection techniques employed here were not then available. Specifically, the proportional counter is capable of detecting individual events for the fact that one primary electron is all that is required to trigger an avalanche. This is in contrast to the relative measurements of ionization currents. Of equal importance is the fact the proportional counter is capable of discriminating against higher order radiation while the ion chamber is not.

It is indeed surprising that certain of the earlier results obtained without the benefits of modern electronics and technique compare as well as they do with the results of this paper.

ACKNOWLEDGEMENTS

The author is greatly indebted to Professor Joyce A. Bearden in whose laboratory this experiment was conducted. His continual assistance and guidance led to many short cuts and helped to remove seemingly insurmountable difficulties.

To Alan J. Bearden who conceived the idea for this study and who originally set up the apparatus I am equally grateful. His techniques and advise proved invaluable as the work progressed.

I would also like to express my gratitude to Calvin Krause for his assistance and superb workmanship in making the necessary parts, and generally helping to keep the apparatus vacuum tight.

Finally I would like to thank W. C. Herrick, YN2 who devoted several of his evenings to make this paper ready for printing.

VITA

The author was born in Buffalo, New York on October 5, 1931. After living for a short time in New York, Virginia, and Santa Fe, New Mexico, his family settled in Menlo Park, California where he received his elementary and secondary education. He entered the U. S. Naval Academy in 1949 and received a Bachelor of Science degree in June of 1953.

From 1953 until 1958 he served in several sea duty billets in the following ships and staffs: USS MISSOURI (BB-63), USS JOHN S. MC CAIN (DL-3), COMDESDIV 212, and USS WILTSIE (DD-712). In 1958 LT Wise was ordered to the U. S. Naval Postgraduate School, Monterey, California to study in the Department of Marine Engineering. In 1959, after one year in Monterey, he began his graduate training in Physics at Johns Hopkins.

The author studied Physics under Professors Bearden, Kerr, Owen, Pevsner, Rasseti, and Yang; and mathematics under Dr. Dwork. This essay is the direct result of the experimental techniques suggested by Professor Bearden and his son Dr. Alan J. Bearden and was accomplished in the Johns Hopkins University laboratory.

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6. Hamner N-401 High Voltage Regulator (stability as reported in ref. 2 above)
7. Hamner N-302 Amplifier
8. Hamner N-270, Decade Scaler and the Hamner N-801 Electronic Clock
9. Woernle, Annalen der Physik, 5, 475 (1930); as it appears in Compton and Allison, X-rays in Theory and Experiment.

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